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[Method and apparatuses for digital imaging]

--METHOD AND APPARATUS FOR DIGITAL IMAGING--

--FIELD OF THE INVENTION--

1. The [object of the invention is] present invention relates to a digital imaging method, in which method the object being imaged is irradiated and the radiation is detected by means of semiconductor sensors covering an area which is substantially smaller than the image-forming surface.

2. [Further objects of the invention are] The present invention further relates to apparatuses for digital imaging, in which imaging a radiation source is used for irradiating the object being imaged, and semiconductor sensors are used for detecting the radiation, whereby the area covered by the semiconductor sensors is substantially smaller than the image-forming surface. A special object of the invention is a mammography apparatus applying this technology.

--BACKGROUND OF THE INVENTION--

3. Different imaging methods are used for a variety of applications. In imaging applications relating to medicine and biotechnology, among others, x-ray, gamma or beta radiation is typically passed through the object being imaged and further onto an image-forming surface. In recent years, alongside conventional film-based imaging methods digital imaging systems have been developed, the said digital imaging methods using semiconductor sensors such as CCD

sensors (Charge Coupled Device) or CMOS sensors (Complementary Metal-Oxide Semiconductor) as the image-forming surface.

4. Mammography is a typical area of application of digital imaging relating to medical technology which requires a large image-forming surface, typically at least of 18 x 24 cm, and also high resolution. In mammography, strict limits are also set for acceptable exposure to radiation. Mammographic imaging also requires an image-forming surface, whose active area extends on three sides as close to the outer edge of the imaging area as possible, in order that the chest and both armpits can be positioned for imaging in such a way that as much tissue as possible can be imaged.

5. Semiconductor sensors are typically made of silicon. One disadvantage of this type of sensor is its high price, since with the increase in size of the sensor, the cost of its manufacture per surface area increases exponentially. The manufacture of one semiconductor sensor thus becomes extremely expensive in applications requiring an extensive image-forming surface.

6. Attempts have been made to avoid the above problem by producing the image-forming surface in a mosaic-like manner from several smaller semiconductor sensors as described, for example, in GB patent publication 2 305 096. In this type of solution, it becomes a problem to obtain a uniform image-forming surface, since one side of a rectangular semiconductor sensor is typically reserved for control couplings. This means that all sides of the sensor cannot be connected to the active area of another sensor, but there will always remain a small gap between them. To compensate for the disadvantages caused by the gaps, various solutions based on lenses

or fibre optics can be used, but the disadvantage of lenses is their poor efficiency and the use of fibre optics incurs major additional costs. In some applications, attempts have been made to solve the problem by producing a sensor with a extensive surface by means of a semiconductor technique based on amorphous silicon, but the resolution obtainable in this manner is not sufficient for medical applications requiring a high level of accuracy, as mammography.

7. A known solution for obtaining a wide image-forming surface is to arrange semiconductor sensors in a chessboard-like fashion in rows and columns so that essentially every other chessboard pattern square comprises a semiconductor sensor in such a way that in one direction, for example parallel to the rows, the sensors extend beyond the chessboard pattern square, and correspondingly in the orthogonal direction, that is, parallel to the columns, there remains a gap between the sensors. In such a case the semiconductor sensor assembly is arranged to be mobile - in a way that the assembly can be moved twice in the direction where there is a gap between the sensors, and the sensor assembly is irradiated in the initial position and after both moves of the assembly. In this way the area covered by the sensor assembly as a whole – excluding the squares remaining on the edges of the image-forming surface – can be imaged by three exposures.

8. The problem with the above arrangement is that the sensor assembly has to be moved and stopped for as many as three different exposures. This means that the mechanical structure of the imaging apparatus becomes difficult to implement, the frequent exposures place a load on the radiation source, and the imaging time is prolonged.

9. To avoid excessive exposure to radiation, in medical applications it is often necessary to arrange for collimation, that is, by means of shadowing, to limit radiation at any time only to the area covered by the sensors. The implementation of collimation then causes a problem area of its own. Since, for example, a typical x-ray source focal spot is not an infinitely small point, but has finite dimensions, for example, of the order 0.3 x 0.3 mm, depending on the structure of the equipment, a half-shadowed area a few millimetres wide is formed at the edges of the radiation field, in which area radiation is incomplete. Because of this, collimation must be planned so that there is a certain amount either of overlap or shortfall at the edge areas, in other words that the areas being imaged either overlap to some extent, or that there is no overlap. However, when the chessboard pattern according to the prior art is used, the overlap causes the radiation dose to double in the lattice-like area, at points even to triple, in the object being imaged, and the shortfall on the other hand forms a lattice-like area in the image being formed, which area has less image information than elsewhere, or where it is completely lacking.

10. The edge areas of the image-forming surface constitute a further problem, since they cannot be irradiated completely. Empty squares remain on the edges of the image-forming surface, that is, image information is obtained only from the area of every other square, in which case the edges of the image-forming surface form a kind of castellated pattern.

--**OBJECTS AND SUMMARY OF THE INVENTION**--

11. The aim of the invention is to develop an imaging method and apparatuses for implementing the method in such a way that the foregoing problems can be solved, or at least the disadvantages caused by them can be diminished. [These aims are achieved by means of the

method and apparatuses, whose characteristic features are defined in the enclosed claims, especially in the characterising parts of the independent claims.]

12. The aims of the invention are achieved especially by arranging the semiconductor sensors so that the entire image-forming surface can be imaged by means of two irradiations, moving the semiconductor sensors only once between the two irradiations.

13. According to one advantageous embodiment of the invention, the semiconductor sensors are arranged so as to form a bar having essentially the shape of a rectangle, so that the said bar comprises several semiconductor sensors - in either one or two columns. The couplings for controlling the semiconductor sensors, and the other couplings needed, are then preferably situated on one side of the sensor.

14. According to a further advantageous embodiment of the invention, the said bars are arranged at a distance from one another to form a sensor matrix so that the distance between the bars is at most equal to the width of the active area of the semiconductor sensors of the said bars.

15. The invention is based on arranging the semiconductor sensors in such a form, preferably rectangular, [- preferably rectangular - form] that by moving the semiconductor sensors from the first position to the second position and by irradiating the object to be imaged in both positions, the entire image-forming surface can be covered, which means that by combining these two images a uniform image of the entire image-forming surface is obtained. By means of a collimator matrix it is possible in both positions to limit radiation only to the area covered by the

semiconductor sensors.

16. An advantage of the method and apparatus according to the invention is the easily implemented mechanical structure as regards both the sensor assembly and collimation. The sensor and collimator assembly can also be made plain to align and of robust structure. As the number of exposures decreases, the thermal stress on the radiation source also decreases, on account of which the cooling of the radiation source does not constitute a significant problem, nor is it necessary to wait for the radiation source to cool, which would slow down imaging work. The time spent on imaging a single object is also reduced since the entire image-forming surface can be covered by just two exposures. Furthermore, the empty squares at the edge of the image-forming surface are eliminated, that is, straight edges are obtained for the image-forming surface, and the disadvantages caused by collimation described above are also less significant than in prior art solutions.

--BRIEF DESCRIPTION OF THE DRAWINGS--

17. The invention is described in greater detail below with the help of its advantageous embodiments and with reference to the enclosed figures, of which figures

Figure 1 shows, by way of an example, an embodiment of the invention in the context of mammographic imaging,

Figure 2a shows one advantageous structure of the sensor bar,

Figure 2b shows another advantageous structure of the sensor bar,

Figure 3 shows one advantageous structure of the sensor matrix, and

Figure 4 shows one advantageous way of forming a sensor bar.

--DETAILED DESCRIPTION OF THE INVENTION--

18. In Figure 1, the application of the invention is described by way of an example in the context of mammographic imaging, but the invention may obviously also be used for any other corresponding digital imaging. According to Figure 1, the semiconductor sensors 1 are arranged to form essentially rectangular sensor bars 2, which sensor bars 2 form a mobile sensor matrix 3. The sensor bars 2 are arranged in the sensor matrix 3 in a fixed position with respect to one another, so that between the sensor bars 2 remains a vacant area narrower than a sensor bar 2. Collimation is carried out by means of essentially rectangular collimators 4, which then form a mobile collimator matrix 5, in which the collimators 4 are placed in a fixed position with respect to one another. The collimator matrix 5 is positioned for imaging in such a way that the collimators 4 shadow the vacant areas between the sensor bars 2 of the sensor matrix 3, as seen from the radiation source 6, in which case no radiation will be focused on these areas. The collimator construction can be situated, as in Figure 1, either in the immediate vicinity of the object being imaged or at a distance from it - even in the immediate vicinity of the radiation source. The object 7 being imaged, in mammography typically the breast, is placed between the collimator matrix 5 and the sensor matrix 3 and the object is irradiated with the radiation from the radiation source 6. The semiconductor sensors 1 detect the radiation they receive, on the basis of which digital image information is formed with the help of a sample and hold circuit 8 and an analog-to-digital converter 9. If necessary, the image information can be edited further, for example, to compensate for dark current and possible non-linearities. The image information is transmitted further either to processing means 10 or memory means 11. After this, and with the object 7 being imaged still remaining in the same position, the sensor matrix 3 is moved in the sideways direction so that the sensor bars 2 will cover essentially the same areas where the

vacant areas between sensor bars 2 were situated before the move. In mammography, the object 7 being imaged, that is, the breast, is kept in place with the help of pressing means (not shown). The collimator matrix 5 is moved correspondingly so that the collimators 4 then shadow the vacant areas between the sensor bars 2 conforming to the new position of the sensor matrix 3. The object 7 being imaged is irradiated for a second time with the new settings of the sensor matrix 3 and collimator matrix 5, and the image information formed on the basis of the second irradiation is combined with the image information formed on the basis of the first irradiation in the processing means 10. By means of two irradiations, therefore, an image of the entire image-forming surface can be obtained.

19. With the solution described above considerable advantages are achieved with respect to the prior art. The mechanical structure according to the invention is easier to implement as regards both the sensor matrix and collimation. The sensor matrix formed of rectangular sensor bars is plain to align and has a robust structure. The collimator matrix is also easy to construct and it is easy to align with respect to the sensor matrix. Furthermore, as the object being imaged is only irradiated twice, the load on the radiation source decreases, which prolongs its service life and speeds up the imaging work, because the need to cool the radiation source is lessened, and the time spent on imaging a single object is also shortened.

20. Compared with a uniform image-forming surface, the arrangement relating to the invention requires only half of the active surface area of the semiconductor sensors. On the other hand, when using, for example, CMOS sensors, the invention can, if so desired, be realised so that no arrangement based on lenses or fibre optics will be needed to compensate for the gaps

between the semiconductor sensors.

21. As the sensor and collimator matrix are only moved once, the accuracy of a move carried out in only one direction needs to be looked after. It is, therefore, possible to dimension and align the collimator matrix in such a way that the overlap of the areas being irradiated is significantly reduced, and thus the disadvantages of collimation are diminished in comparison to known solutions.

22. The final formation of a digital image can be carried out by connecting the imaging equipment with a computer, in which case the computer's memory and processing means can be utilised. The processing means 10 relating to Figure 1 can also be realised, for example, by a dedicated Application Specific Integrated Circuit (ASIC), to which are connected memory means 11, for example, a FLASH memory. The formation of final image information is known as such to a person skilled in the art, and its more detailed description is not necessary for the implementation of the invention.

23. According to one advantageous embodiment of the invention, the sensor bars 2 to be placed in the sensor matrix 3 are formed of semiconductor sensors 1, which are substantially smaller than the sensor bars 2. Figures 2a and 2b show two advantageous ways of arranging the semiconductor sensors 1 to form a sensor bar 2. In both figures, the sensor bar 2 comprises semiconductor sensors 1a, 1b, ..., which are arranged to form a rectangular sensor bar 2. A typical semiconductor sensor 1n comprises an active area A, which is used for detecting the radiation received, and a coupling area K, through which the control signals of the sensor 1n and

the charge readout, that is, in this case the collection of image information, are transmitted. In a semiconductor 1n, at least one side is typically reserved for the coupling area K, and thus the semiconductor sensor 1n can advantageously be connected to another semiconductor sensor 1n on three sides, as shown in Figure 2b, if it is desirable that the active areas of the sensors form a uniform surface. The sensor bar 2 can thus be formed of either one (1 x N) or two (2 x N) columns of semiconductor sensors 1n. The distance between sensor bars 2 in the sensor matrix 3 is determined on the basis of the width #A of the active area A of the semiconductor sensors 1 used, in other words, the maximum distance between the sensor bars 2 can, in the case of single column sensor bars 2, equal the width #A of A (Figure 3), or in the case of sensor bars with two columns, 2 x the width of A, that is, 2 x #A.

24. When the sensor bar 2 is formed of semiconductor sensors 1n which are substantially smaller than the sensor bar 2, no large and therefore expensive semiconductor sensors are required. Further cost savings ensue from the fact that if a single semiconductor sensor 1n is damaged, it can be replaced without having to replace the entire sensor bar 2.

25. Figure 3 shows an advantageous manner of arranging the sensor bars 2 according to the invention, so that the image-forming surface is made as large as possible and the edges of the image-forming surface become uniform. The sensor bars 2 consist of one column (1 x N) of semiconductor sensors 1n, in which case the outermost sensor bars 2 are placed so that the coupling area K of the semiconductor sensors 1n is placed towards the inside of the sensor matrix 3. The image-forming surface will then extend over the entire area covered by the sensor matrix 3 and the so-called castellated pattern will not be formed on the edges of the image-

forming surface. The positioning of the coupling areas of the sensor bars 2 inside the sensor matrix 3 may be selected freely, provided that the vacant areas between the sensor bars are correctly dimensioned. The sensor bars 2 may obviously also be formed of two columns (2 x N) of semiconductor sensors 1n, but if the outermost sensor bars 2 are also formed in this manner, the active area of the sensor matrix 3 cannot be made to extend sideways all the way to the edges of the image-forming surface.

26. An application of the invention may obviously also be envisaged where a sensor matrix is constructed of different types of sensor bars, that is, for example sensor bars with active areas of varying widths, one or two columns, having coupling areas on opposite sides and/or even sensor bars based on different technologies. However, and especially if this type of sensor bar is used in applications where radiation has to be limited to the sensor matrix area, some of the advantages obtained with the invention may be lost.

27. According to one advantageous embodiment of the invention, the movements of the collimator matrix and sensor matrix are not connected to each other, but each matrix is moved separately. This is preferably done by first moving the sensor matrix into its new position and then aligning the collimator matrix according to the sensor matrix. The invention may, however, naturally also be implemented so that the movements of the collimator matrix and sensor matrix are synchronised.

28. The movement of the sensors and/or collimators may be carried out, for example, by means of solenoids or separate servomotors. The use of a solenoid is especially recommended

since it is an economical, accurate and reliable component. The invention particularly makes it possible to use solenoids since, according to the invention, the sensors and/or collimators need to be moved only between two positions.

29. According to one advantageous embodiment of the invention, the semiconductor sensors are CMOS sensors based on direct detection of radiation, the said sensors having certain advantages compared with conventional semiconductor sensors. With the CMOS sensors improved resolution is achieved compared with conventional semiconductor sensors and due to the parallel bus type data transfer, they enable more rapid transfer of image information. CMOS technology is the most widely applied semiconductor technology, which means that the availability of CMOS circuits is good, and their production costs will fall as the technology develops.

30. Figure 4 shows an advantageous way, in accordance with the invention, of forming the sensor bar of CMOS sensors. The CMOS sensors 13, 14,... are connected to a preferably rectangular radiation detector 12 with substantially the same external dimensions as the bar. The detector 12 is preferably made of doped silicon (Si) or a cadmium zinc telluride compound (CdZnTe). Between the top and bottom surfaces of the detector is generated a biasing voltage Ur, by means of which the charge generated by the radiation is collected to the nearest pixel. The charge generated is transmitted to the CMOS sensors 13, 14, ..., which are connected to the detector 12, preferably by means of microscopic ball conductors, that is, by means of so-called bump bonding. In the coupling area of the CMOS sensors, control signals can be fed to the sensors and the radiation detected can be read by means of pins at the end of the sensors, for the

purpose of forming image information. The detection of radiation by means of CMOS sensors is known as such to a person skilled in the art.

31. In accordance with the invention, semiconductor sensors known as such, which are based on the use of lenses or fibre optics, can obviously also be used, in which case the coupling areas can also be located in the three-dimensional structure of the sensor on a surface that allows the whole width of the sensor to be utilised as an active radiation-detecting area. This means, however, that some of the advantages achieved with the invention are at the same time lost.

32. Although the invention is described above by way of an example in the context of mammography, it can obviously also be used in connection with any other similar imaging application. In accordance with the invention, any radiation that is detectable by semiconductor sensors can be used.

33. The invention is particularly useful in imaging applications relating to medical technology, where x-ray or gamma radiation is typically used, and in biotechnical applications where beta radiation is typically used. The invention is furthermore applicable to industrial testing and quality control methods utilising radioscopy.

34. It is obvious to a person skilled in the art that as technology develops, the basic idea of the invention can be implemented in various ways, which means that its different embodiments are not limited to the foregoing examples, but may vary within the scope of protection defined in the enclosed claims.

--ABSTRACT--

A digital imaging method, in which the object being imaged is irradiated and the radiation is directed by means of semiconductor sensors (1), covering an area which is smaller than the image-forming surface. The semiconductor sensors (1) are arranged in such a way that the image-forming surface can be imaged in two irradiations by moving the semiconductor sensors (1) between the irradiations. The radiation can be limited to the area covered by the sensors (1) by means of collimators (4). The semiconductor sensors (1) are arranged to form advantageously rectangular bars (2), which comprise several semiconductor sensors (1) in the form of one or two columns, in which the bars (2) are arranged advantageously at a distance from one another, the distance between the bars being at most equal to the width of the active area of the semiconductor sensors of the bars.